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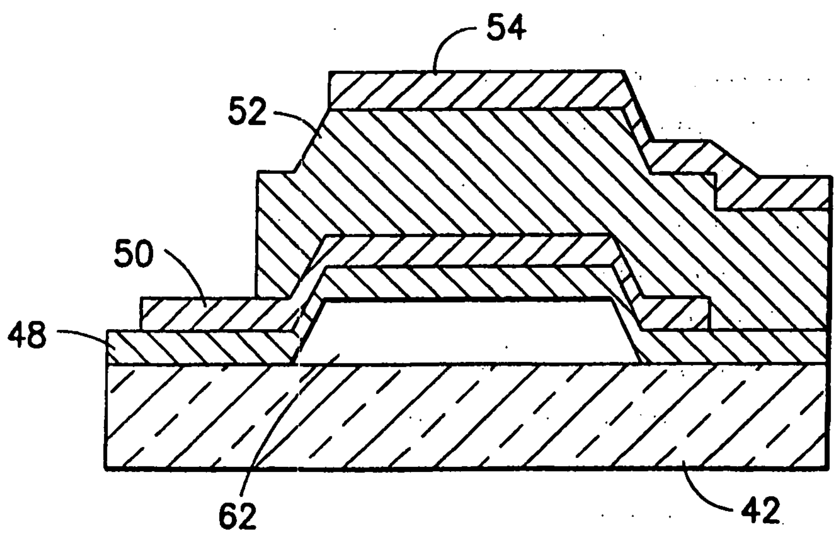
(54) Title: METHOD FOR FABRICATING FBARS ON GLASS SUBSTRATES

(57) Abstract



A method for fabricating a Thin Film Bulk Acoustic Wave Resonator (FBAR). The method comprises the steps of: (A) forming a sacrificial layer (62) comprising one of a metal and a polymer over a selected portion of a substrate (42); (B) forming a protective layer (48) on the sacrificial layer and on selected portions of the substrate; (C) forming a bottom electrode layer (50) on a selected portion of the protective layer; (D) forming a piezoelectric layer (52) on a selected portion of the protective layer; (E) forming a top electrode (54) on a selected portion of the piezoelectric layer; and (F) removing the sacrificial layer (62) to form an air gap. The use of a metal or a polymer material to form sacrificial layers has several advantages over the use of zinc-oxide (ZnO) to form such layers. In accordance with a further aspect of the invention, an FBAR is provided which includes a glass substrate. The use of glass to form substrates offers several advantages over the use of other materials to form substrates. For exemple, most types of glass are less expensive than semiconductor materials, and exhibit low permitivity characteristics, and low parasitic capacitances. In addition, most glass materials are substantially loss free when being used in microwave frequency applications.

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"Method for fabricating FBARS on glass substrates"

FIELD OF THE INVENTION:

The invention relates to resonators and, in particular, the invention relates to a method for fabricating Thin Film Bulk Acoustic Wave Resonators (FBARs).

BACKGROUND OF THE INVENTION:

It is known to construct Thin Film Bulk Acoustic Wave Resonators (FBARs) on semiconductor wafers including those which are comprised of Silicon (Si) or gallium arsenide (GaAs). For example, in an article entitled "Acoustic Bulk Wave Composite Resonators", Applied Physics Lett., Vol. 38, No. 3, pp. 125-127, Feb. 1, 1981, by K.M. Lakin and J.S. Wang, an acoustic bulk wave resonator is disclosed which comprises a thin film piezoelectric layer of Zinc-Oxide (ZnO) sputtered over a thin membrane of Silicon (Si).

Unfortunately, semiconductor materials have high conductivities and high dielectric permittivity characteristics. These characteristics can have a deleterious effect on piezoelectric coupling efficiency and resonator quality factors, as is described in an article entitled "Temperature Compensated High Coupling and High Quality Factor ZnO/SiO_2 Bulk Wave Resonators on High Resistance Substrates", IEEE Ultrasonics Symp., 1984, pp. 405-410, by T. Shiosaki, T. Fukuichi, M. Tokuda, and A. Kawabata.

It is known to reduce ohmic losses exhibited by semiconductor wafers by using semi-insulating semiconductor wafers, as is evidenced by an article entitled "Coplanar Waveguides and Microwave Inductors on Silicon Substrates", IEEE Trans. Microwave Theory Tech., vol. 43, no. 9, pp. 2016-2021, 1995, by Adolfo C. Reyes, Samir M. El-Ghazaly, Steve J. Dorn, Michael Dydyk, Dieter K. Schroder, and Howard Patterson. However, the use of these types of wafers necessitates the use of expensive special grade materials, and does not eliminate the presence of stray capacitances.

Additionally, semiconductor wafers and crystalline wafers need to be carefully polished after being cut from a crystal in order to smooth their surfaces. The polishing process can be expensive.

It would be advantageous to provide a substrate that is formed of a low cost material and which exhibits a low permittivity characteristic and low parasitic capacitances. It would also be advantageous to provide a substrate that is formed of a material that does not need to be polished in order to smooth its surfaces.

It is known to construct so called "bridge" structures on FBAR substrate surfaces using a sacrificial layer that is formed of zinc-oxide (ZnO), as is evidenced by an article entitled "An Air-Gap Type Piezoelectric Composite Thin Film Resonator", IEEE Proc. 39th Annual Symp. Freq. Control, pp. 361-366, 1985, by Hiroaki Satoh, Yasuo Ebata, Hitoshi Suzuki, and Choji Narahara. Similarly, in an article entitled "Multi-layered Ultrasonic Transducers Employing Air-Gap Structure", IEEE Trans. Ultrason. Ferroelec. Freq. Control, vol. 42, no. 3, May 1995, by Susumu Yoshimoto, Masamichi Sakamoto, Ken-ya Hashimoto, and Masatsune Yamaguchi, a multi-layered ultrasonic transducer is

disclosed which includes an air gap formed by the removal of a "sacrificial" ZnO layer.

During the fabrication of these types of FBARs, a sacrificial layer of ZnO are deposited (e.g., sputtered) over a substrate. The sacrificial layer is later removed via an etching step that is performed after all of the layers of the FBAR have been completely formed. One drawback of this process is that the steps of sputtering and forming the sacrificial layer can be tedious and time-consuming. This is because ZnO is a ceramic material, and thus is brittle and has a low thermal conductivity. If, by example, very high power is employed during the sputtering of the ZnO, the "target" substrate may break. Also, the growth rate of the ZnO must be controlled to produce a correct crystal orientation and crystallite size distribution. Thus, the growth rate may need to be limited to only 2μm/h.

Another drawback of using a sacrificial layer formed of ZnO is that the surface of the crystalline ZnO film is textured, and thus causes acoustic energy scattering losses to occur within the FBAR. Also, the textured surface of the ZnO may cause the surface of a layer (e.g., the bridge layer) formed over the sacrificial ZnO layer to become deformed. A further drawback of employing a sacrificial layer of ZnO is that during the etching of the layer to form an air gap, a piezoelectric ZnO layer that is formed on the sacrificial layer can become damaged.

In view of these problems, it can be appreciated that it would be advantageous to provide a method for fabricating an FBAR using a sacrificial layer that is formed of a material having characteristics that are more beneficial than those of ZnO and other materials conventionally used to form sacrificial layers.

OBJECTS OF THE INVENTION:

It is a first object of this invention to provide a Thin Film Bulk Acoustic Wave Resonator (FBAR) having a sacrificial layer that is formed of a material that has more beneficial characteristics than conventional materials that are used to form sacrificial layers.

It is a second object of this invention to provide an improved method for fabricating a Thin Film Bulk Acoustic Wave Resonator (FBAR).

It is a third object of this invention to provide a Thin Film Bulk Acoustic Wave Resonator (FBAR) having a substrate that is formed of a material that has more beneficial characteristics than conventional materials that are used to form substrates.

Further objects and advantages of this invention will become apparent from a consideration of the drawings and ensuing description.

SUMMARY OF THE INVENTION

The foregoing and other problems are overcome and the objects of the invention are realized by a method for fabricating a Thin Film Bulk Acoustic Wave Resonator (FBAR). The method of the present invention employs a sacrificial layer that is comprised of either a metal or polymer material instead of a conventionally-used material such as, by example, zinc-oxide (ZnO). The use of these materials to form sacrificial layers has many advantages over the use of ZnO to form these layers.

In accordance with the method of the invention, a first step includes sputtering a metal such as, be example, copper (Cu) over a substrate. The sputtered Cu is then

patterned to form a sacrificial layer.

A next step includes depositing silicon dioxide (SiO_2) over the sacrificial layer and over selected portions of the substrate to form a first SiO_2 layer (also referred to as a "first protective layer"). This layer may not be needed in cases in which the piezoelectric layer comprises a material which will not be detrimentally affected by the etching of the sacrificial layer (which will be described below). Thereafter, a metallic material such as, by example, gold (Au) is deposited over a selected portion of the first SiO_2 layer. The deposited gold is then patterned to form a bottom electrode layer.

A next step includes depositing zinc-oxide (ZnO) over a selected portion of the bottom electrode layer, and over a selected portion of the first SiO_2 layer. The ZnO is then patterned to form a ZnO layer (also referred to as a "piezoelectric layer").

A next step of the process includes depositing a further metallic material such as, by example, gold, over a selected portion of the ZnO layer. Thereafter, the deposited gold is patterned to form a top electrode layer. In appropriate cases, a second protective layer may also be formed on the structure to protect the piezoelectric layer during the formation of the vias and/or during the etching of the sacrificial layer which will be described below.

Vias are then formed in the structure so that the sacrificial layer can be removed. Thereafter, the sacrificial layer is removed through the vias to form an air gap.

The fabrication process of the invention may also be performed using a sacrificial layer that is comprised of a

polymer instead of a metal. The steps of this process are similar to those described above, except that the steps of depositing, patterning, and removing the sacrificial layer (e.g., the polymer) are performed in a different manner. By example, the step of depositing the polymer is performed by spinning the polymer onto the substrate. The polymer is then patterned to form the sacrificial layer. After each of the other layers and the vias of the FBAR have been formed in the same manner as described above, the sacrificial layer is removed to form the air gap.

The type of polymer used to form the sacrificial layer is preferably one that can withstand the high temperatures that can be reached during the sputtering of the ZnO layer.

In accordance with another aspect of the invention, the method for fabricating FBARs may be performed by removing the sacrificial layer prior to the deposition of the material forming the ZnO layer. For this method, the same steps described above are performed, except that after the first SiO_2 layer and the bottom electrode layer have been formed, the sacrificial layer is then removed to form the air gap in the same manner as described above. Thereafter, the steps of forming the ZnO layer and the top electrode layer are carried out in the same manner as described above.

The use of metals and polymers to form sacrificial layers has many advantages over the use of most conventionally-used materials including, by example, ZnO. For example, FBARs having sacrificial layers that are comprised of metals or polymers can be fabricated more quickly than the FBARs having sacrificial layers formed of ZnO. Also, metals and polymers generally have smoother surfaces than ZnO. Moreover, metals and polymers can be etched using chemicals that are not harmful to piezoelectric layers

formed of, by example, ZnO.

In accordance with a further aspect of the invention, an FBAR is provided which includes a glass substrate. The FBAR is formed of similar layers as the FBARs described above, and may be fabricated in accordance with the method of the invention. The use of glass to form substrates offers several advantages over the use of other materials to form substrates. Glass is inexpensive and thus can be used to form substrates having large surface areas at an inexpensive cost. Also, most glass materials exhibit low permittivity characteristics and low parasitic capacitances. Moreover, most glass materials become substantially loss free when used in microwave frequency applications.

A further advantage of using glass to form substrates is that, unlike semiconductor materials, glass can have inherently smooth surfaces and thus requires little or no polishing.

BRIEF DESCRIPTION OF THE DRAWINGS

The above set forth and other features of the invention are made more apparent in the ensuing Detailed Description of the Invention when read in conjunction with the attached Drawings, wherein:

Fig. 1a illustrates a cross section of an exemplary FBAR having a glass substrate.

Fig. 1b illustrates a table showing permittivities for various types of materials.

Fig. 2a illustrates a top view of a portion of an exemplary

FBAR having vias.

Fig. 2b illustrates a cross section of a portion of an exemplary FBAR.

Fig. 3a illustrates a cross section of a portion of a Thin Film Bulk Acoustic Wave Resonator (FBAR) that is formed in accordance with a step of a fabrication process of the invention, for a case in which the portion of the FBAR comprises a sacrificial layer formed of Copper (Cu).

Fig. 3b illustrates a cross section of the FBAR Fig. 3a as it appears after a further step of the fabrication process performed in accordance with the invention.

Fig. 4 illustrates a cross section of the FBAR of Fig. 3b as it appears after a further step of the fabrication process performed in accordance with the invention.

Fig. 5 illustrates a cross section of the FBAR resonator of Fig. 4 as it appears after a further step of the fabrication process performed in accordance with the invention.

Fig. 6a illustrates a cross section of a portion of Thin Film Bulk Acoustic Wave Resonator (FBAR) that is formed in accordance with a step of the fabrication process of the invention, for a case in which the portion of the FBAR comprises a sacrificial layer formed of a polymer material.

Fig. 6b illustrates a cross section of the FBAR Fig. 6a as it appears after a further step of the fabrication process performed in accordance with the invention.

Fig. 7 illustrates a cross section of the FBAR of Fig. 6b as it appears after a further step of the fabrication

process performed in accordance with the invention.

Fig. 8 illustrates a cross section of the FBAR of Fig. 7 as it appears after a further step of the fabrication process performed in accordance with the invention.

Fig. 9a illustrates a cross section of a portion of a Thin Film Bulk Acoustic Wave Resonator (FBAR) that is formed in accordance with a step of an alternate fabrication process of the invention.

Fig. 9b illustrates a cross section of the FBAR Fig. 9a as it appears after a further step of the alternate fabrication process of the invention.

Fig. 10 illustrates a cross section of the FBAR of Fig. 9b as it appears after a further step of the alternate fabrication process of the invention.

Fig. 11 illustrates a cross section of the FBAR resonator of Fig. 10 as it appears after a further step of the alternate fabrication process of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The inventors have developed an improved method for fabricating Thin Film Bulk Acoustic Wave Resonators (FBARs) having air gaps. Unlike most of the conventional methods for fabricating FBARs, which employ sacrificial layers formed of, by example, zinc-oxide (ZnO), the method of the present invention employs a sacrificial layer that is comprised of either a metal or a polymer material. The use of these materials to form sacrificial layers has many advantages over the use of ZnO to form these layers, as will be described below.

The method of fabricating FBARs in accordance with the invention can be understood in view of Figs. 3a-5. As a first step of the fabrication process, a metal such as, by example, copper (Cu) is sputtered or otherwise deposited over a substrate 42. It is assumed that the substrate is comprised of glass, in accordance with an aspect of this invention which will be further described below, although any other suitable solid material may be employed. The sputtered Cu is then patterned so that it has a thickness of, by example, approximately 2000nm, thereby forming bridges.

Thereafter, the Cu is wet etched to form tapered edges 44a and 44b. In this manner, a sacrificial layer (also referred to as a "base layer") 44 is formed.

It should be noted that other metals may be used in lieu of copper to form the sacrificial layer 44. By example, the sacrificial layer 44 may be formed of aluminum, zinc, antimony, and any of the elements in the periodic table extending from titanium to copper, from yttrium to silver, and from lanthanum to gold. Ideally, the metals used to form the layer 44 are low cost and can be etched without great difficulty.

Referring to Fig. 3b, a next step includes depositing silicon-dioxide (SiO_2) over the sacrificial layer 44 and over selected portions of the substrate 42 to form a first SiO_2 layer (also referred to as a "first protective layer") 48 having a thickness of, by example, approximately 300nm. Thereafter, a metallic material such as, by example, gold (Au) is deposited over the a selected portion of the first SiO_2 layer 48. The deposited gold is then patterned to form a bottom electrode layer 50 having a thickness of, by example, approximately 300 nm. Other suitable electrically conductive metallic and non-metallic materials can also be

employed.

It should be noted that for cases in which the material used to form the piezoelectric layer (to be described below) is not detrimentally effected by the etching of the sacrificial layer (the etching of the sacrificial layer will be described below), it is not necessary to employ the first protective layer 48, and the bottom electrode layer may be formed directly over the sacrificial layer 44 and selected portions of the substrate 42.

Referring to Fig. 4, a next step includes depositing zinc-oxide (ZnO) over a selected portion of the bottom electrode layer 50, and over a selected portion of the first SiO_2 layer 48. The ZnO may be deposited by, for example, sputtering from a target in a mixture of Argon (Ar) and O_2. After the ZnO is deposited, it is patterned to form a ZnO layer (also referred to as a "piezoelectric layer") 52 having a selected thickness (e.g., approximately 2000nm) that is a function of a desired resonant frequency of the FBAR.

A next step of the process includes depositing a further metallic material such as, by example, gold, over a selected portion of the ZnO layer 52. Thereafter, the deposited gold is patterned to form a top electrode layer 54, which is illustrated in Fig. 5. As with the first electrode layer 50, other suitable electrically conductive metallic and non-metallic materials can also be employed.

Vias are then formed in the structure so that the sacrificial layer 44 can be removed. The vias may be formed in any suitable manner. For example, and referring to Fig. 2a, selected portions of the first SiO2 layer 48 may be removed to provide openings 47 and 49 for accessing the sacrificial layer 44 (tapered edges 44a and 44b are

shown). It should be noted that in cases where it is appropriate to protect the piezoelectric layer 52 during the creation of the vias and/or the removal of the sacrificial layer, a second layer of SiO_2 (also referred to as a "second protective layer") (not illustrated in Fig. 2a) may be employed. By example, SiO_2 may be deposited and patterned on a selected portion of the piezoelectric layer 52 after the piezoelectric layer 52 has been formed and before the top electrode layer 54 has been formed. The SiO_2 is then patterned to form a contact area on a top portion of the ZnO layer 52. Within the contact area the top electrode layer 54 is then formed. In other cases where it is appropriate, the second protective layer may instead be formed after the formation of the top electrode layer 54 on the piezoelectric layer 52.

Vias may also be formed in the structure according to the example shown in Fig. 2b. For this example, holes may be formed in the ZnO layer 52 by an using an acid etchant. Selected portions of the FBAR and the surrounding wafer may then be covered by depositing a second protective layer of SiO_2 51 via, for example, a plasma-enhanced chemical vapor deposition (CVD). The SiO_2 is then patterned in fluorine plasma (F plasma) to form a contact area on a top portion of the ZnO layer 52. Then, the top electrode layer 54 is formed over the contact area and over portions of the second layer of SiO_2 51. Thereafter, selected portions of the second layer of SiO_2 51 and selected portions of the first SiO2 layer 48 are patterned to form vias (via 49' is shown in Fig. 2b). For this example, it should be noted that as described above with respect to Fig. 2a, instead of depositing and patterning the second protective layer 51 prior to the formation of the top electrode layer 54, the second protective layer 51 may be deposited and patterned after the formation of the top electrode layer 54.

A next step of the fabrication process includes removing the sacrificial layer 44 through the vias by wet etching to form an air gap 62. The etching may be performed by using, for example, acids, alkalis, or redox reactions (e.g., ferric chloride). Either selective or non-selective etching may be used.

In order to determine whether the device is correctly tuned, the electrical performance characteristics of the device can then be measured in a suitable manner and compared with a model of the device. Any suitable technique may be employed for modeling the device including that disclosed in an article entitled "Systematic Design of Stacked-Crystal Filters by Microwave Network Methods", IEEE Trans. Microwave Theory Tech., vol. MTT-22, pp. 14-25, Jan. 1974, by Arthur Ballato, Henry L. Bertoni, and Theodor Tamir.

Figs. 6a-8 illustrate steps of the fabrication process of the invention using a sacrificial layer that is formed of a polymer instead of a metal. The steps of this process are similar to those described above, except that the steps of depositing, patterning, and removing the sacrificial layer (e.g., the polymer) are performed in a different manner. Referring to Fig. 6a, by example, the step of depositing the polymer is preferably performed by spinning the polymer onto the substrate 42 thereby providing an inherently smooth surface for further processing. The polymer is then patterned so that it has a thickness of, by example, approximately 1000nm, thereby forming bridges. The polymer is also etched to form tapered edges 44a and 44b in a similar manner as described above. In this manner, sacrificial layer 60 is formed. After each of the other layers and the vias of the FBAR have been formed in the same manner as described above (Figs. 6b and 7), the sacrificial layer 60 is then removed by, for example,

etching or plasma ashing. In this manner, air gap 62 is formed, which is illustrated in Fig. 8.

For cases in which organic polymers are used to form the sacrificial layer 60, the sacrificial layer 60 can be etched in, by example, a plasma containing oxygen. For cases in which silicone polymers are used, for example, an addition of fluorine may be necessary.

Also, some types of polymers can be dissolved in organic solvents (e.g., acetone). Unlike the corrosive chemicals that are used for, by example, anisotropic etching of silicon, organic solvents do not attack ZnO. Thus, polymers which can be dissolved by organic solvents are preferred. Also, the use of this type of bridge structure avoids drawbacks that can associated with the performance of, by example, deep anisotropic etching of silicon, which requires the etching of a large surface area because the etch stopping crystal plane is angled at, by example, only 54.74 degrees with respect to the surface of the wafer.

The type of polymer used to form the sacrificial layer 60 is also preferably one that can withstand the high temperatures that can be reached during the sputtering of the ZnO layer 52. The polymer may be, by example, polytetrafluoroethylene or a derivative thereof, polyphenylene sulfide, polyetheretherketone, poly(para phenylene benzobismidazole), poly(para phenylene benzobisoxazole), poly (para phenylene benzobismidazole), poly (para phenylene benzobisthiazole), a polyimide, polyimide siloxane, vinyle ethers, polyphenyl, parylene-n, parylene-f, benzocyclobutene.

In accordance with another aspect of the invention, the method for fabricating FBARs may be performed by removing the sacrificial layer prior to the deposition of the

material forming the ZnO layer 52. This may be understood in view of Figs. 9a-11 wherein portions of an exemplary FBAR that is formed in accordance with this method of the invention are illustrated. The FBAR includes a sacrificial layer 44 formed of, by example, copper (Cu). For this method, the same steps described above are performed, except that after the first SiO_2 layer 48, the bottom electrode layer 50, and the vias have been formed, the sacrificial layer 44 is then removed to form the air gap 62 in the same manner as described above. Thereafter, the steps of forming the ZnO layer 52 and the top electrode layer 54 are carried out in the same manner as described above.

The use of metal or polymer materials to form sacrificial layers enables the fabrication process to be performed more quickly than the fabrication processes employing sacrificial layers that are formed of, by example ZnO. This is because ZnO is a brittle ceramic material and thus requires more time to be deposited than metals or polymers which are not as brittle as ZnO.

The use of polymers or metals to form sacrificial layers also avoids problems that can be associated with the use of most conventionally-used materials (e.g., zinc-oxide) to form such layers. By example, unlike some materials, metals have small grain sizes, and thus have naturally smooth surfaces. Also, polymers can be spun-on during the fabrication of FBAR structures, and develop smooth surfaces during baking while the polymer reflows in a liquid state. As a result, the layer formed over the polymer sacrificial layer does not experience surface deformations that are as serious as those which can occur to layers deposited over most conventionally-used materials (e.g., ZnO).

Another advantage of using metals or polymers to form

sacrificial layers instead of, by example, ZnO is that metals and polymers can be etched using chemicals that are not harmful to the ZnO layer 52.

In accordance with a further aspect of the invention, an FBAR is provided which includes a glass substrate 42, as is illustrated in Fig. 1a. The FBAR is formed of similar layers as the FBARs described above, and may be fabricated in accordance with the method of the invention.

The use of glass to form substrates offers several advantages over the use of semiconductor materials to form substrates. One advantage is that glass is inexpensive. Thus, glass can be used to form chips having large surface areas at an inexpensive cost, thus providing more surface area for bonding. Active components such as, by example, transistors and integrated circuits (ICs) can be added onto the chips by, for example, flip-chip technology.

Also, most glass materials including, by example, silicate glass, have low permittivity characteristics, and hence exhibit low parasitic capacitances. Thus, unlike semiconductor materials, which normally have high conductivities and high dielectric permittivity characteristics, glass substrates do not exhibit detrimental characteristics such as, by example, low piezoelectric coupling efficiencies and low resonator quality factors. Fig. 1b illustrates a table showing the respective permittivities of various types of materials.

In addition, most glass materials except, by example, soda-lime glass, are substantially loss free when being used in microwave frequency applications.

A further advantage of using glass to form substrates is that, unlike semiconductor materials, most glasses have

naturally smooth surfaces. Thus, little or no polishing is required to smooth the surfaces of glass substrates as is required to smooth the surfaces of substrates formed of semiconductor materials.

Moreover, the thermal expansion characteristics of most types of glass materials are more similar to those of the other materials forming the FBAR layers than are the thermal expansion characteristics of, by example, silicon. As such, in a bonding application, a component may be encapsulated in glass.

It should be noted that the types of technologies that are available for micromachining glass substrates are not as diverse as those available for micromachining substrates formed of crystalline semiconductor materials.

While the invention has been particularly shown and described with respect to preferred embodiments thereof, it will be understood by those skilled in the art that changes in form and details may be made therein without departing from the scope and spirit of the invention.

CLAIMS

What is claimed is:

1. A method for fabricating a Thin Film Bulk Acoustic Wave Resonator (FBAR), comprising the steps of:

STEP A: forming a sacrificial layer on a selected portion of a substrate, wherein the sacrificial comprises one of a metal and a polymer;

STEP B: forming a bottom electrode layer on the sacrificial layer and on selected portions of the substrate;

STEP C: forming a piezoelectric layer on a selected portion of the bottom electrode layer and on a selected portion of the substrate;

STEP D: forming a top electrode layer on a selected portion of the piezoelectric layer;

STEP E: removing the sacrificial layer to form an air gap beneath at least a portion of the bottom electrode layer.

2. A method as set forth in Claim 1, wherein STEP A is performed by the steps of:

STEP 1: depositing one of the metal and the polymer over the substrate; and

STEP 2: patterning the deposited one of the

metal and the polymer to form the sacrificial layer.

3. A method as set forth in Claim 2, wherein STEP E is performed by etching the sacrificial layer using a chemical that is not harmful to the piezoelectric layer.

4. A method as set forth in Claim 1, wherein STEP A is performed by the steps of:

STEP 1: depositing the metal over the substrate; and

STEP 2: patterning the deposited metal to form the sacrificial layer.

5. A method as set forth in Claim 4, wherein the sacrificial layer has a thickness of about 2000nm.

6. A method as set forth in Claim 4, wherein the metal is copper (Cu).

7. A method as set forth in Claim 1, wherein STEP A is performed by the steps of:

STEP 1: spinning the polymer onto the substrate; and

STEP 2: patterning the polymer to form the sacrificial layer.

8. A method as set forth in Claim 7, wherein the sacrificial layer has a thickness of about 1000nm.

9. A method as set forth in Claim 1, wherein between the performances of STEPs D and E, a step is performed of:

forming at least one via through at least one of the layers formed in STEPS B-D so that the sacrificial layer can be removed through the at least one via.

10. A method as set forth in Claim 1, wherein the protective layer comprises SiO_2 having a thickness of about 300nm.

11. A method as set forth in Claim 1, wherein the bottom electrode layer comprises an electrically conductive metal having a thickness of about 300nm.

12. A method as set forth in Claim 1, wherein the piezoelectric layer comprises zinc-oxide (ZnO) having a thickness of about 2000nm.

13. A method as set forth in Claim 1, wherein the top electrode layer is comprised of an electrically conductive metal having a thickness of about 300nm.

14. A method as set forth in Claim 1, wherein the sacrificial layer is formed of the metal, and wherein STEP E is performed by wet etching the sacrificial layer.

15. A method as set forth in Claim 1, wherein the sacrificial layer is formed of the polymer, and wherein STEP E is performed by one of the steps of etching the sacrificial layer and plasma ashing the sacrificial layer.

16. A method as set forth in Claim 1, wherein the polymer material can survive the performance of STEP C at an elevated temperature.

17. A method as set forth in Claim 1, wherein the substrate is comprised of a solid material.

18. A method as set forth in Claim 1, wherein STEP E is performed between the performances of STEP B and STEP C.

19. A method as set forth in Claim 1, wherein the piezoelectric layer comprises zinc-oxide (ZnO) having a thickness that is a function of a desired resonant frequency of the FBAR.

20. A method as set forth in Claim 1, wherein the substrate is comprised of a glass.

21. A method for fabricating a Thin Film Bulk Acoustic Wave Resonator (FBAR), comprising the steps of:

STEP A: forming a sacrificial layer on a selected portion of a substrate, wherein the sacrificial comprises one of a metal and a polymer;

STEP B: forming a first protective layer on the sacrificial layer and on selected portions of the substrate;

STEP C: forming a bottom electrode layer on a selected portion of the first protective layer;

STEP D: forming a piezoelectric layer on a selected portion of the bottom electrode layer and on a selected portion of the first protective layer;

STEP E: forming a top electrode layer on a selected portion of the piezoelectric layer;

STEP F: removing the sacrificial layer to form an air gap beneath at least a portion of the bottom electrode layer.

22. A method as set forth in Claim 21, wherein between the performances of STEPs D and E, a further step is performed of forming a second protective layer over selected portions of the piezoelectric layer so that a portion of the second protective layer and a top portion of the piezoelectric layer form a contact area, and wherein STEP E is performed by forming the top electrode layer within the contact area.

23. A method as set forth in Claim 21, wherein between the performances of STEPs E and F, a further step is performed of forming a second protective layer over selected portions of the piezoelectric layer.

24. A Thin Film Bulk Acoustic Wave Resonator (FBAR), comprising:

a substrate comprised of glass;

a piezoelectric layer;

a bottom electrode layer, at least a portion of said bottom electrode layer being located between a selected portion of said substrate and a selected portion of said piezoelectric layer;

a top electrode layer formed on a top portion of said piezoelectric layer.

25. A Thin Film Bulk Acoustic Wave Resonator (FBAR) as set forth in Claim 24, further comprising:

a protective layer formed over portions of said substrate;

wherein said piezoelectric layer is formed atop a second selected portion of said protective layer and atop said portion of said bottom electrode layer; and

wherein a first selected portion of said substrate and a first selected portion of said protective layer define an air gap therebetween.

26. A Thin Film Bulk Acoustic Wave Resonator (FBAR) as set forth in Claim 25, wherein said air gap is formed by a removal of a sacrificial layer comprised of one of a polymer and a metal.

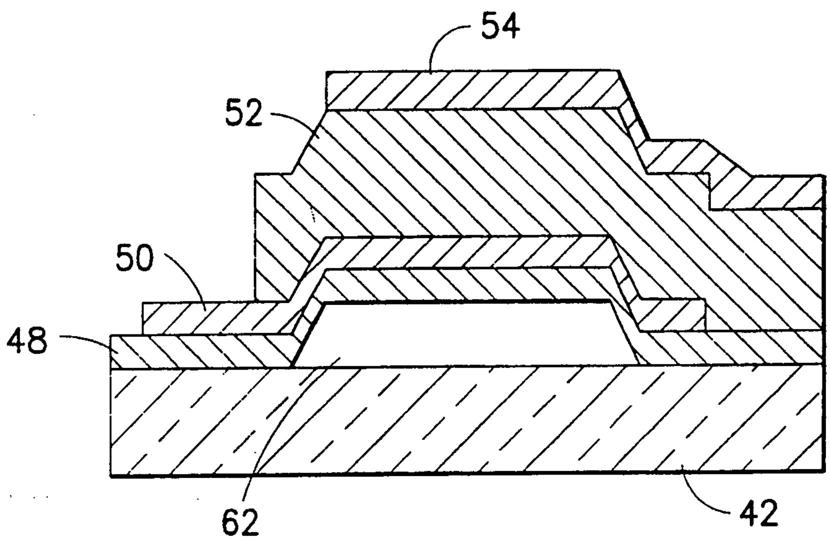

FIG. 1a

MATERIAL	RELATIVE PERMITTIVITY
BOROSILICATE GLASS	4.0
SILICA GLASS	3.78
ALUMINUM SILICATE GLASS	6.3
LEAD ALKALI GLASS	9.5
ALUMINA	8.8
SILICON	11.8
GALLIUM ARSENIDE	10.9
GERMANIUM	16

FIG. 1b

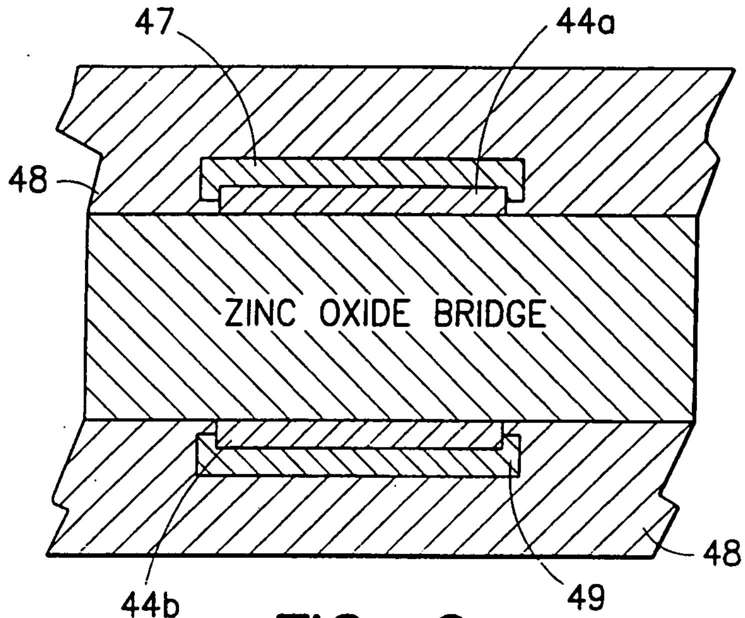
47
44a
48
ZINC OXIDE BRIDGE
48
44b
49

FIG. 2a

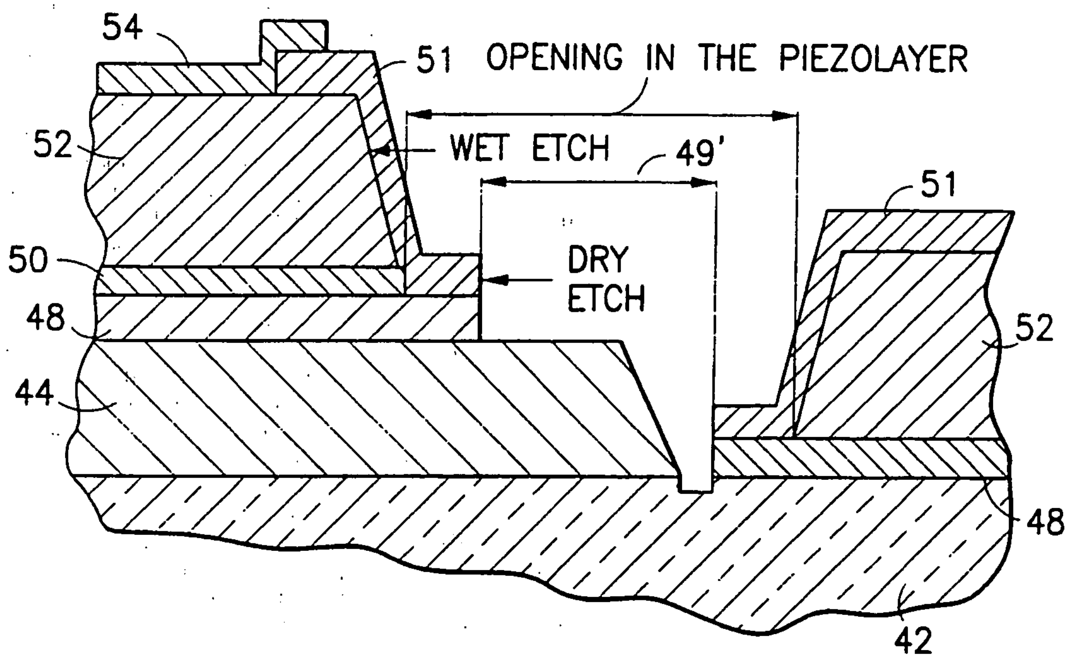
54
51 OPENING IN THE PIEZOLAYER
52
WET ETCH
49'
51
50
DRY
ETCH
48
52
44
48
42

FIG. 2b

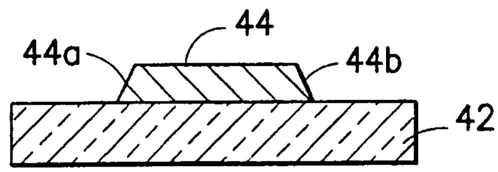

FIG. 3a

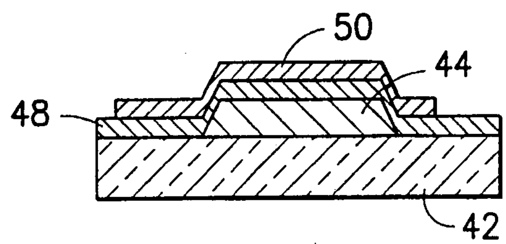

FIG. 3b

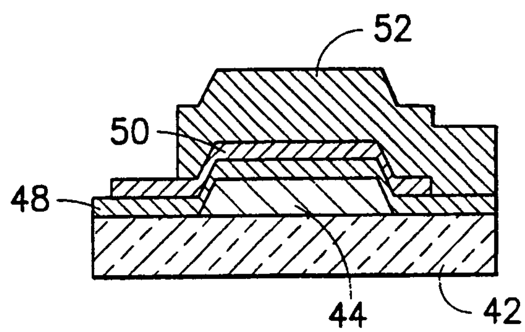

FIG. 4

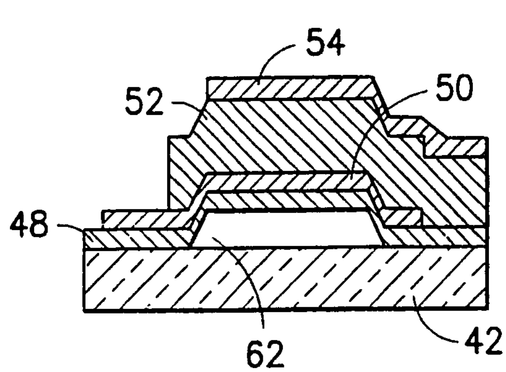

FIG. 5

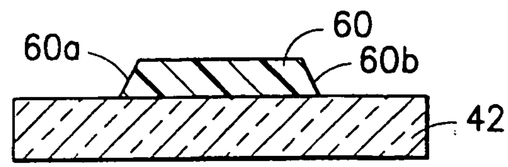

FIG. 6a

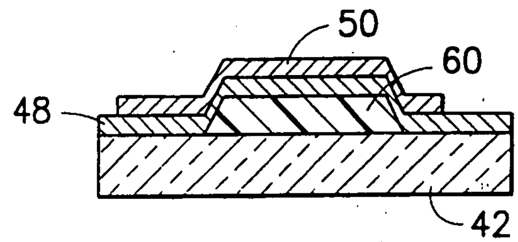

FIG. 6b

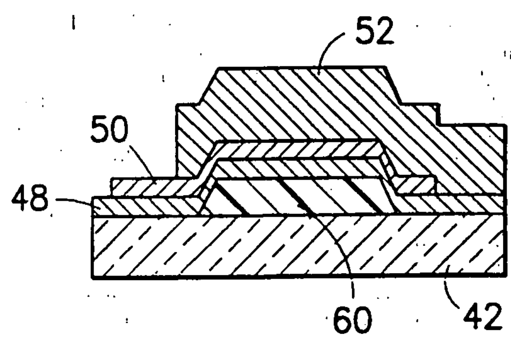

FIG. 7

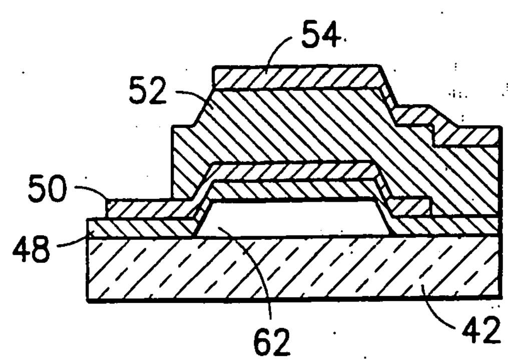

FIG. 8

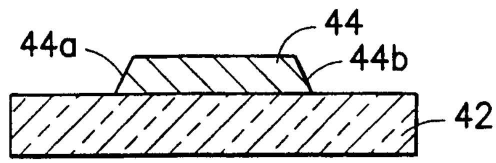

FIG. 9a

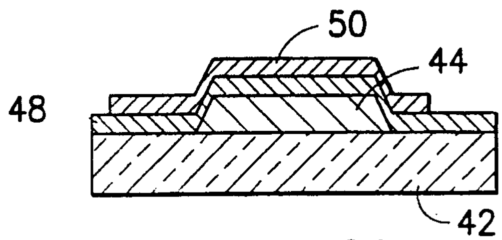

FIG. 9b

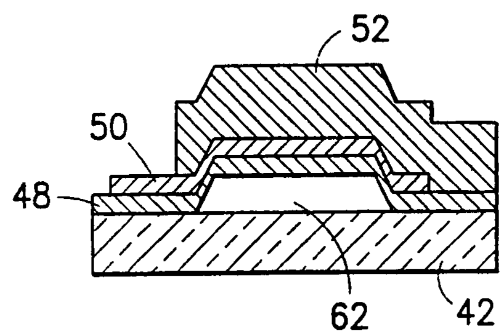

FIG. 10

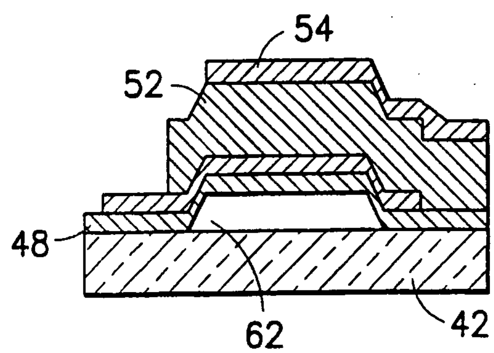

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/16231

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :HO1L 41/08
US CL :310/312
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 310/311, 312, 324, 366

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P	US 5,596,239 A (DYDYK) 21 January 1997 (21.01.97). See entire document.	1-26
X	US, 5,162,691 A (MARIANI) 10 November 1992 (10.11.92). See entire document.	1-26
X	US, 4,642,508 A (SUZUKI ET AL) 10 February 1987 (10.02.87). See entire document.	1-26

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
17 NOVEMBER 1997

Date of mailing of the international search report
03 DEC 1997

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MARK BUDD
Telephone No. (703) 308-1929

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/16231

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1-23 A method of fabricating a Thin Film Bulk Acoustic Wave Resonator (FBAR)

24-26 A Thin Film Bulk Acoustic Wave Resonator

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest
☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.